Development of a Robotic Comanipulation and Teleoperation System for Vitreoretinal Surgery

A. Gijbels[1], E.B. Vander Poorten[1], P. Stalmans[2], D. Reynaerts[1]
[1]Dept. of Mechanical Engineering, Katholieke Universiteit Leuven, Belgium
[2]Dept. of Ophthalmology, University Hospitals Leuven, Belgium
Email: andy.gijbels@mech.kuleuven.be

I. Vitreoretinal Surgery

During vitreoretinal surgery, the surgeon performs procedures at the retina which acquire extreme precision. For some diseases, the most appropriate treatment is even too difficult to be performed manually and alternative but less effective treatments need to be applied. One of those diseases is called Retinal Vein Occlusion (RVO). Retinal Vein Occlusion is an eye condition which affects an estimated 16.4 million adults worldwide [1]. The disease occurs when a clot is formed in a retinal vein. This causes the patient to slowly lose his/her sight. Fig. 1 shows a healthy retina on the left and a retina suffering from RVO on the right. Today, there is no proven effective treatment available for this disease [2]. A promising treatment is retinal vein cannulation. During this procedure the surgeon inserts a needle through the sclera and injects a small dose of t-PA, a clot-dissolving agent, directly into the blocked vein [3]. Fig. 2 conceptually demonstrates this procedure. Several research groups report successful cannulations in animal and human models. However, due to safety issues, the procedure is not performed clinically today. The needle needs to be inserted in a vein with a diameter smaller than 500 µm and kept there for several minutes for the fluid to be fully injected [4]. Unintended movements make it extremely difficult to insert and maintain the needle into the vein. They can cause serious damage to the retina during this procedure. Two relevant types of unintended movements can be distinguished. Firstly, the human suffers from physiological tremor. Hand vibrations with an rms amplitude of 182 µm during vitreoretinal procedures have been reported [5]. Secondly, the eye tends to rotate during the procedure due to the lateral forces applied by the instrument on the incision point. These rotations cause the retina to move which makes the surgeon to aim at a dynamic target.

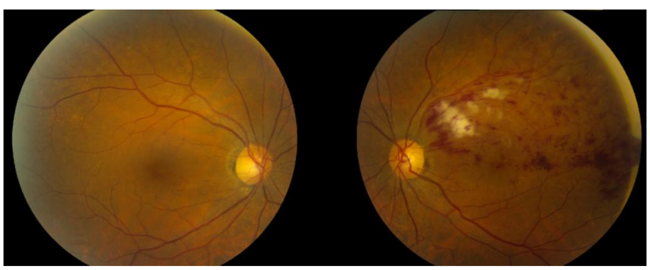

Fig. 1. Retinal Vein Occlusion (RVO): when a retinal vein gets blocked, the circulation of blood through the affected vein is reduced or stopped. The blockage causes the walls of the vein to leak blood and excess fluid into the retina. When the fluid collects in the macula (the area of the retina responsible for central vision), vision becomes blurry.
Left: healthy retina. Right: retina with RVO.

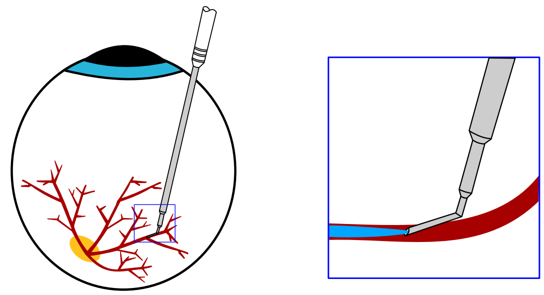

Fig. 2. Retinal Vein Cannulation: a hollow needle is inserted through the sclera and used to inject a clot-dissolving agent directly into the affected vein to remove the blockage causing RVO.

II. Robot-assisted retinal cannulations

Abovementioned problems can be overcome by attaching the instrument to a surgical manipulator that assists the surgeon during the procedure. The manipulator can hold the eye stationary during the procedure by virtue of a Remote Center of Motion (RCM) incorporated in the manipulator. An RCM is a geometric point at a fixed location about which the instrument can pivot and translate through without a physical joint being present at this location [6]. When this RCM is made to coincide with the incision point in the sclera, the degrees of freedom (DOFs) of the instrument will be restricted to three rotations Θ, Φ and Ψ around the RCM and a translation R through the RCM as shown in Fig. 3. In this way, the eye and thus the retina are stabilized such that aiming at the blocked vein becomes easier.

Several surgical manipulators for vitreoretinal surgery have been reported [7]–[12]. Most of those, using a mechanism to implement the RCM, fail to keep the end-effector compact enough due to the kinematics of these mechanisms. This is problematic because of the very confined workspace typically for vitreoretinal surgery. The operating scene is populated by the patient, the surgeon and the microscope that the surgeon

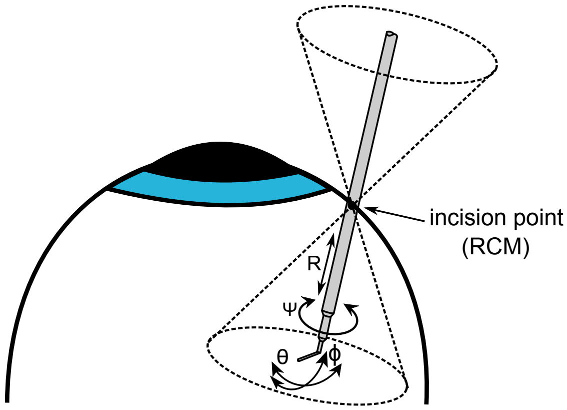

Fig. 3. Vitreoretinal surgeons only need 4 DOFs to manoeuvre the instrument in the eye: three rotations Θ, Φ and Ψ around the incision point and a translation R through the incision point. The remaining DOFs, which cause unintended eye rotations, can be blocked by aligning the RCM of the surgical manipulator with the incision point.

uses to navigate the instruments inside the patient's eye. To overcome these space limitations, an innovative RCM mechanism is incorporated in the surgical manipulator allowing a compact construction of the manipulators end-effector (see Fig. 4).

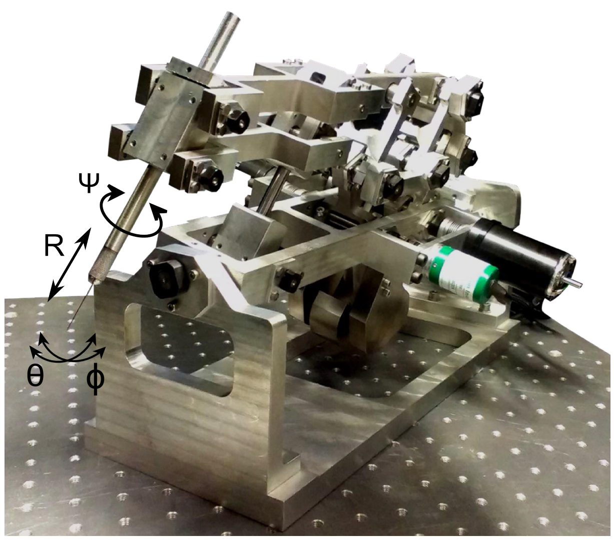

Fig. 4. The surgical manipulator relies on a novel RCM mechanism which implements the translational DOF of the instrument at the base of the mechanism instead of implementing it at the end-effector. In this way the end-effector is held very compact which is particularly interesting for retinal surgery where the instrument needs to be manoeuvred in a highly confined space.

The surgeon can choose to co-operatively move the instrument by gripping and manipulating the instrument directly (comanipulation strategy) or to control the movements of the surgical manipulator indirectly using a joystick (teleoperation strategy). For this purpose, the surgical manipulator is actuated in all its DOFs. When using the comanipulation strategy, virtual damping is implemented in the surgical manipulator to filter out the unintended hand vibrations. This damping also slows down the intended movements facilitating a slow and precise approach of the vein. When using the teleoperation strategy, motion scaling is used to scale down the hand vibrations and to slow down the intended hand movements. For this purpose a 4 DOF haptic joystick was developed (see Fig. 5). The DOFs of this joystick correspond to those shown on Fig. 3. Because of the haptic property of the joystick, scaled force feedback of the interaction forces between the instrument and the retina is possible. In this way, the surgeon is able to feel forces which are normally to small for humans to perceive. This feature will be implemented in the near future using a force sensor integrated in the surgical instrument. Currently, we are testing both the comanipulation and the teleoperation system to determine which technique is the most appropriate one for robotic vitreoretinal surgery.

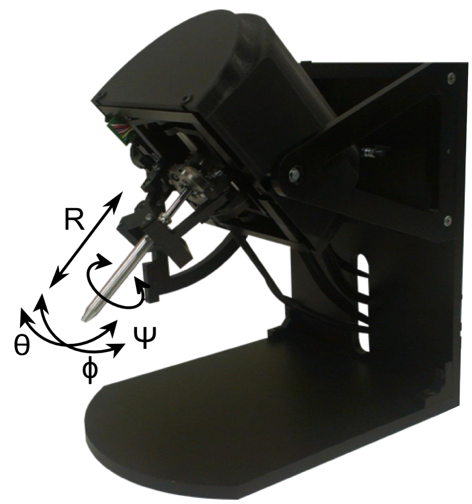

Fig. 5. The kinematical design of the joystick is such that its DOFs correspond to those used during vitreoretinal surgery. The movements of the joystick handle are mapped on the movements of the needle rather than on the movements of the instrument handle. In this way motion inversion between the movements of the surgeon and the instrument, which is typical for this kind of surgery, is eliminated.

III. Acknowledgments

This work was supported by an FP7-People Marie Curie Reintegration Grant, PIRG03-2008-231045 and by a PhD grant from the Institute for the Promotion of Innovation through Science and Technology in Flanders (I.W.T.-Vlaanderen), 101445.

References

[1] R. Sophie, "The prevalence of retinal vein occlusion: Pooled data from population studies from the united states, europe, asia, and australia," *Ophthalmology*, vol. 117, pp. 313– 319, 2010.

[2] B. Nilufer and B. Cosar, "Surgical treatment of central retinal vein occlusion," *Acta Ophthalmologica*, vol. 86, pp. 245–252, 2008.

[3] L. A. Bynoe, R. K. Hutchins, H. S. Lazarus, and M. A. Friedberg, "Retinal endovascular surgery for central retinal vein occlusion: Initial experience of four surgeons," *Retina*, vol. 25, pp. 625–32, 2005.

[4] M. R. Glucksberg, R. Dunn, and C. P. Giebs, "In vivo micropuncture of retinal vessels," *Graefe's Archive for Clinical and Experimental Ophthalmology,*, vol. 231, pp. 405–407, 1993.

[5] C. N. Riviere and P. S. Jensed, "A study of instrument motion in retinal microsurgery," *Proc. of the 22nd Annual EMBS Int. Conf.*, 2000.

[6] G. Zong, X. Pei, J. Yu, and S. Bi, "Classification and type synthesis of 1-dof remote center of motion mechanisms," *Mechanism and Machine Theory*, vol. 43, pp. 1585 – 1595, 2008.

[7] W. Wei, R. Goldman, N. Simaan, H. Fine, and S. Chang, "Design and theoretical evaluation of micro-surgical manipulators for orbital manipulation and intraocular dexterity," *ICRA*, pp. 3389–3395, 2007.

[8] K. Grace, J. Colgate, M. Glucksberg, and J. Chun, "A six degree of freedom micromanipulator for ophthalmic surgery," *IEEE Int. Conf. on Robotics and Automation*, vol. 1, pp. 630–635, 1993.

[9] M. Wapler, V. Urban, T. Weisener, J. Stallkamp, M. Durr, and A. Hiller, "A stewart platform for precision surgery," *Transactions of the Institute of Measurement & Control*, vol. 25-4, p. 329, 2003.

[10] Y. Ida, N. Sugita, T. Ueta, Y. Tamaki, K. Tanimoto, and M. Mitsuishi, "Microsurgical robotic system for vitreoretinal surgery," *Int. Conf. of Computer Assisted Radiology and Surgery*, pp. 27–34, 2012.

[11] A. Uneri, M. Balicki, J. Handa, P. Gehlbach, R. Taylor, and I. Iordachita, "New steady-hand eye robot with microforce sensing for vitreoretinal surgery research," *Int. Conf. on Biomedical Robotics and Biomechatronics*, pp. 814–819, 2010.

[12] Meenink, H.C.M., Rosielle, P.C.J.N., Steinbuch, and M. Smet, "Instrument manipulator for a master-slave robot for vitreo-retinal ophthalmic surgery," *Proc. of the 21st Int. Conf. on Medical Innovation and Technology 2009, Romania,*, p. 53.